IR Thermography of International Space Station Radiator Panels

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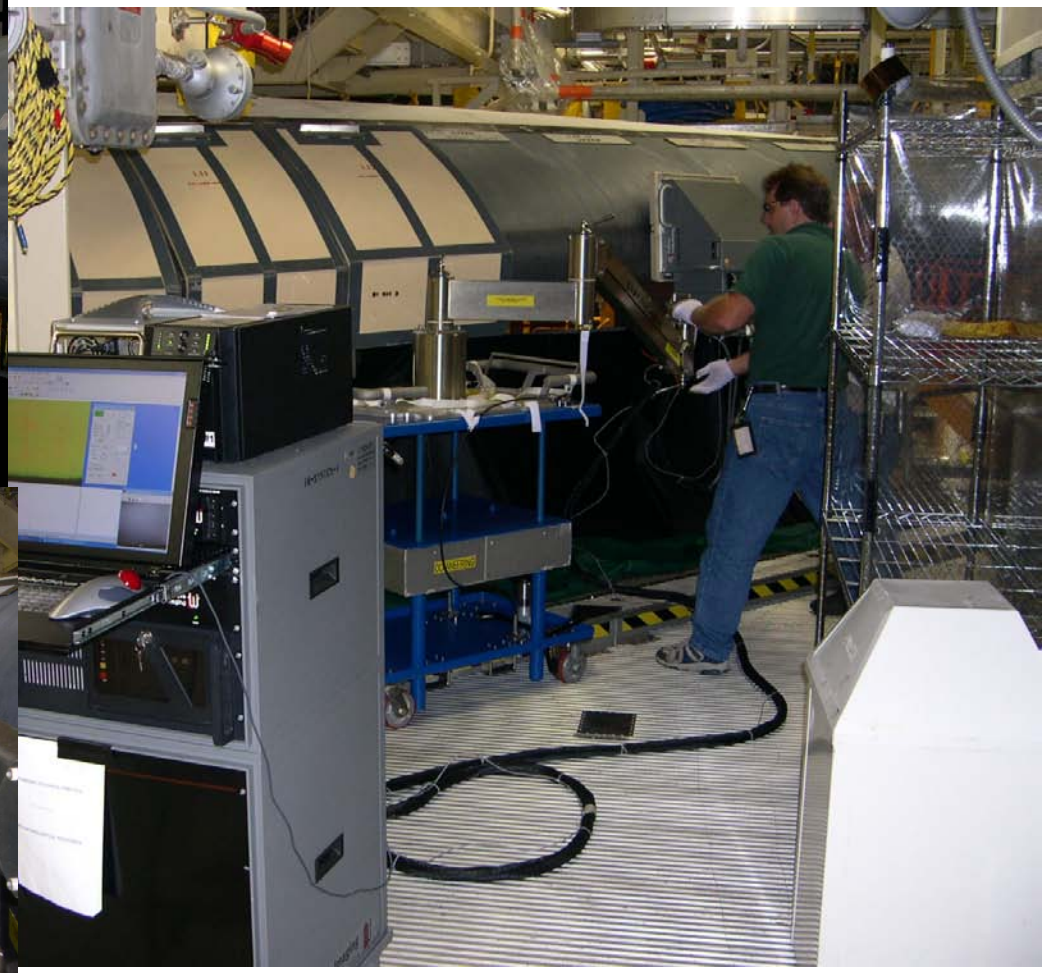
Outline

- Background
  - ISS radiator anomaly
- IR Technique configurations
  - 1. On-orbit IR camera technique
  - 2. Ground IR camera technique
- International Space Station ISS radiator on-orbit IR measurement and analysis
  - Alignment of data
  - Filtering of data
  - Comparison of panels
- Ground IR measurement and analysis on qualification test radiator panels
  - Derivative and contrast image analysis

Ground IR Inspection System for Space Shuttle Orbiter

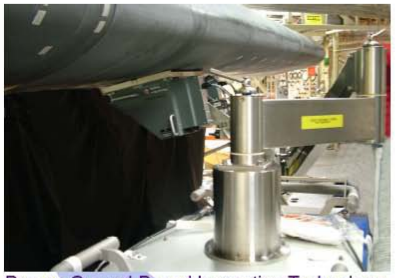
Space Shuttle Orbiter Wing Leading Edge IR Inspection using Flash Heating



Phoenix Mid-wave Camera,
Wavelength = 3 to 5 micron

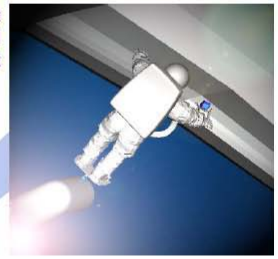
National Aeronautics and Space Administration

Development of On-Orbit Wing-Leading-Edge Inspection



Proven Ground-Based Inspection Technology

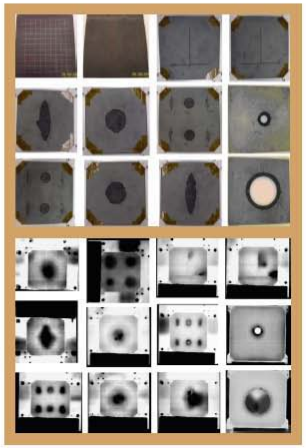
On-Orbit Operational Concept



FLIR Thermacam S65
Wavelength ~ 9 micron

Flight Hardware Developed to Perform Orbital Inspection

Jointly Developed Project by Langley Research Center, Goddard Space Flight Center, and Johnson Space Center



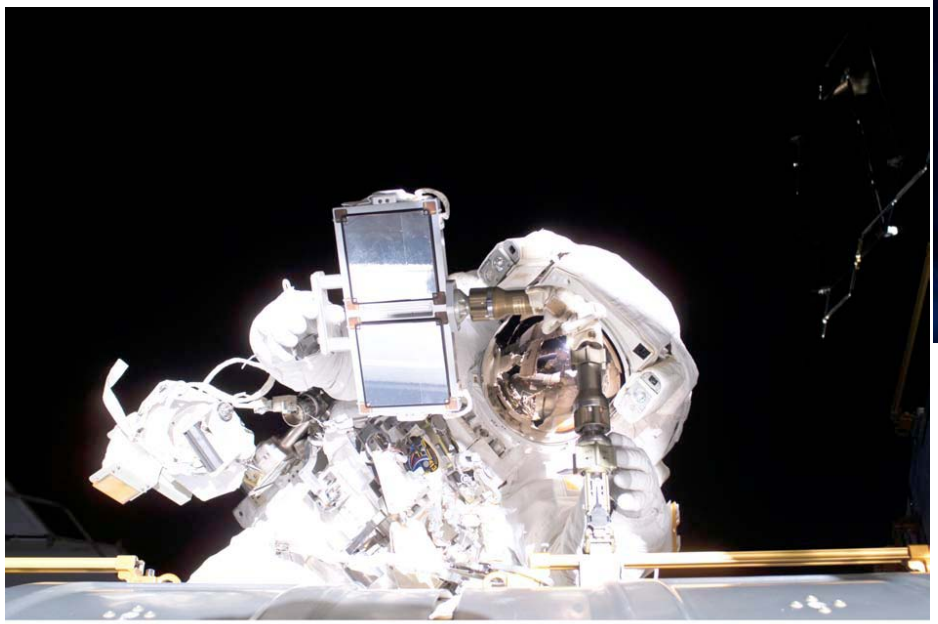
Data Obtained Under Simulated Orbital Conditions

Top: Photographs; Lower: Processed IR images

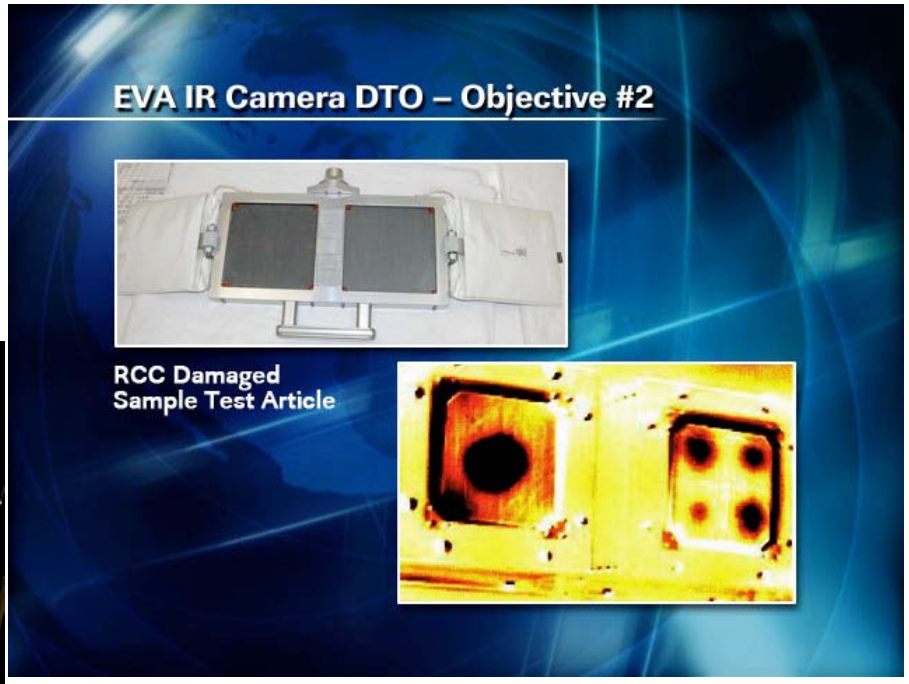
www.nasa.gov

ISS External Vehicular Activity

Sunlight as a heat source



ISS013E63434



IR Images
Detect Damage

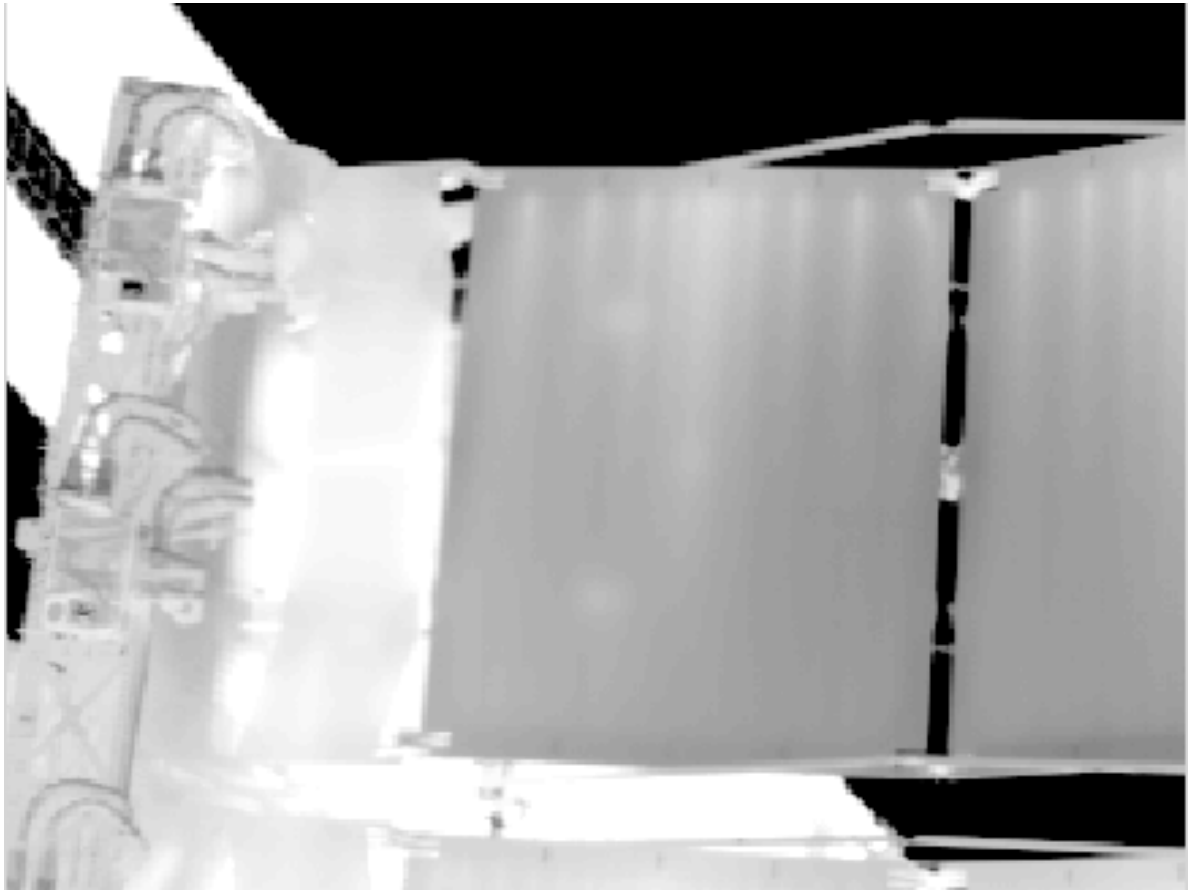
International Space Station (ISS)

Damage to Radiator Panel Detected September 2008

Peeled facesheet

Panel size 10f t x 10 ft

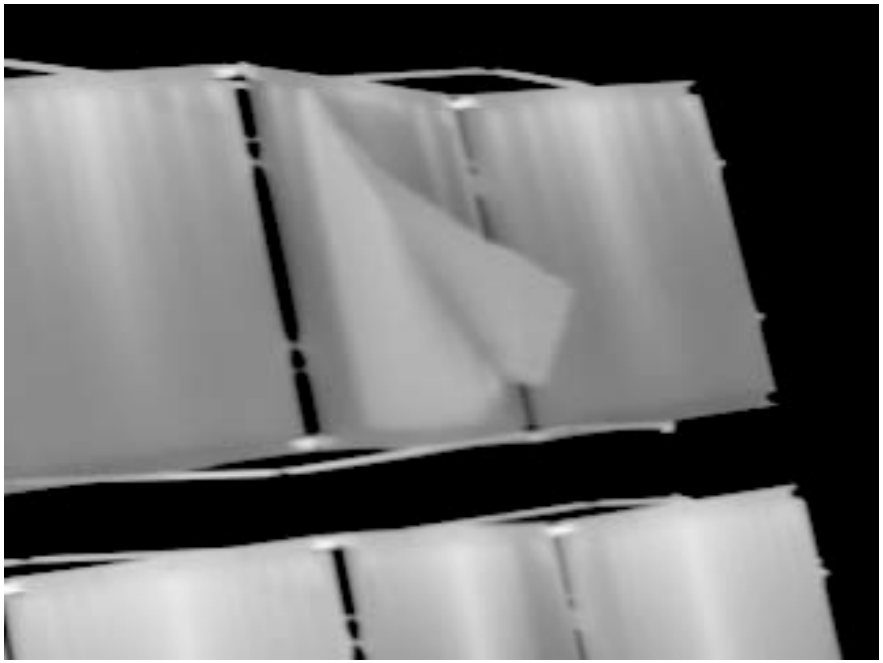
Infrared Images of Radiator Panels



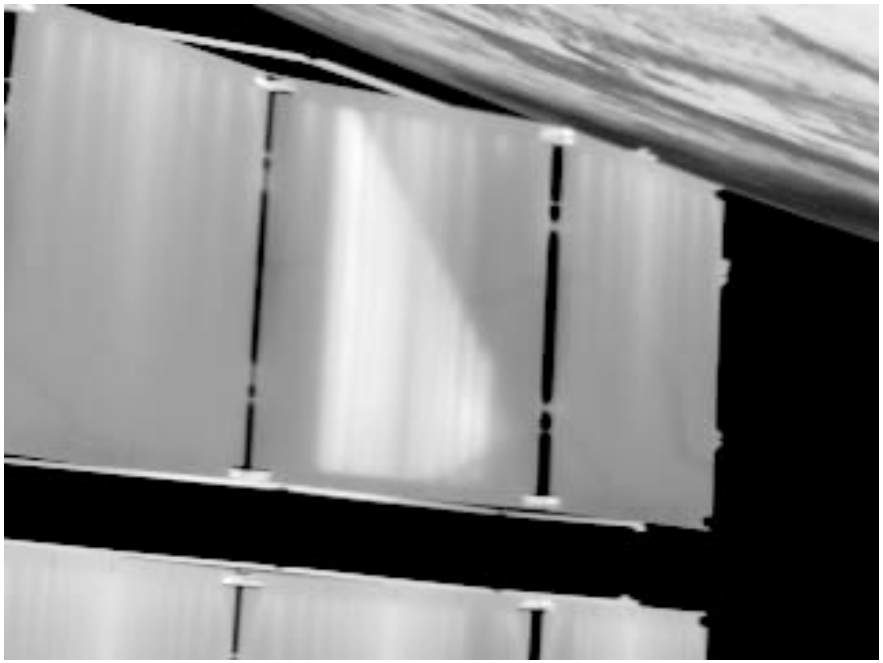
Space walk performed and EVA IR camera used to obtain IR data on both sides of all radiators (48 panels)

On-orbit Infrared Images of Radiator Panels

Peeled side



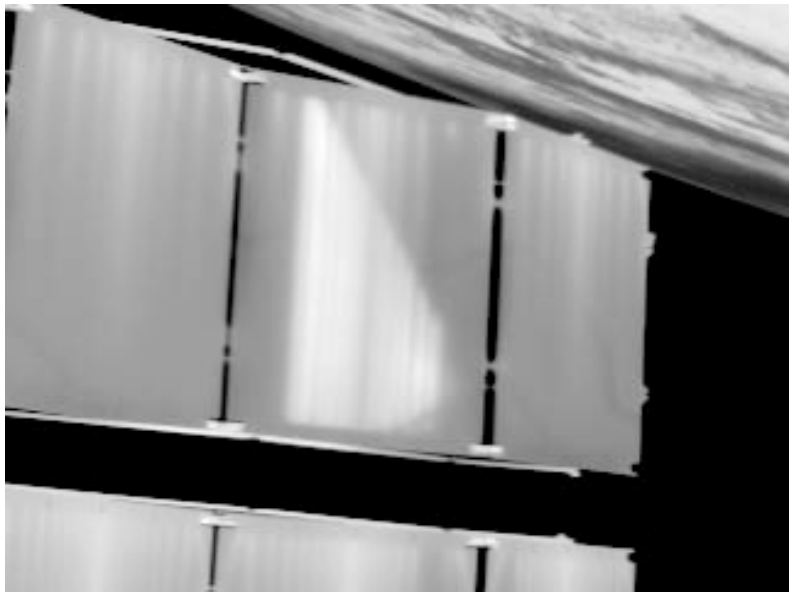
Back side



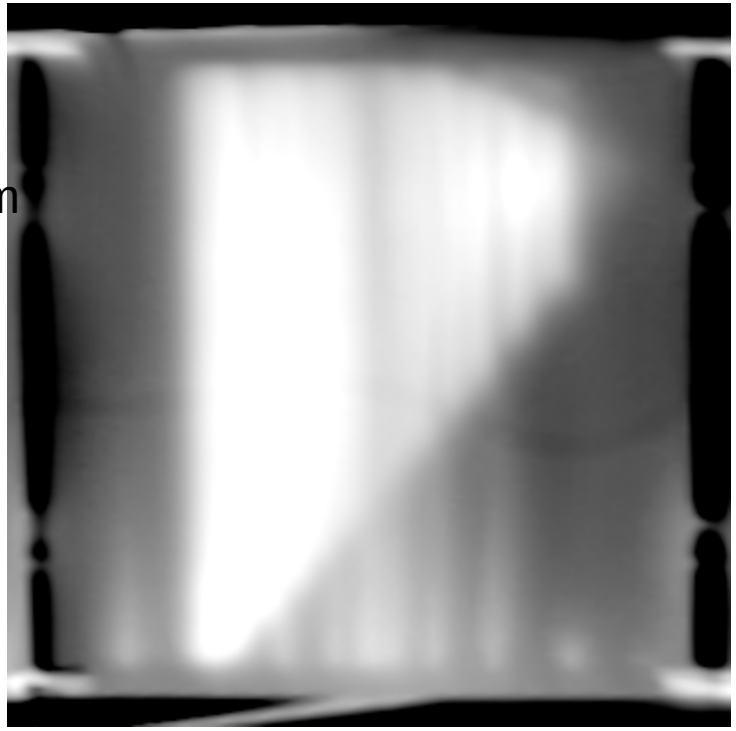
Light areas are warmer
Black areas - space

Transformation of Images to Simplify Panel Comparisons

Panel images need to be transformed so that panel sides are aligned with sides of the image and magnification is fixed
Aligned images allow easy comparison between panels



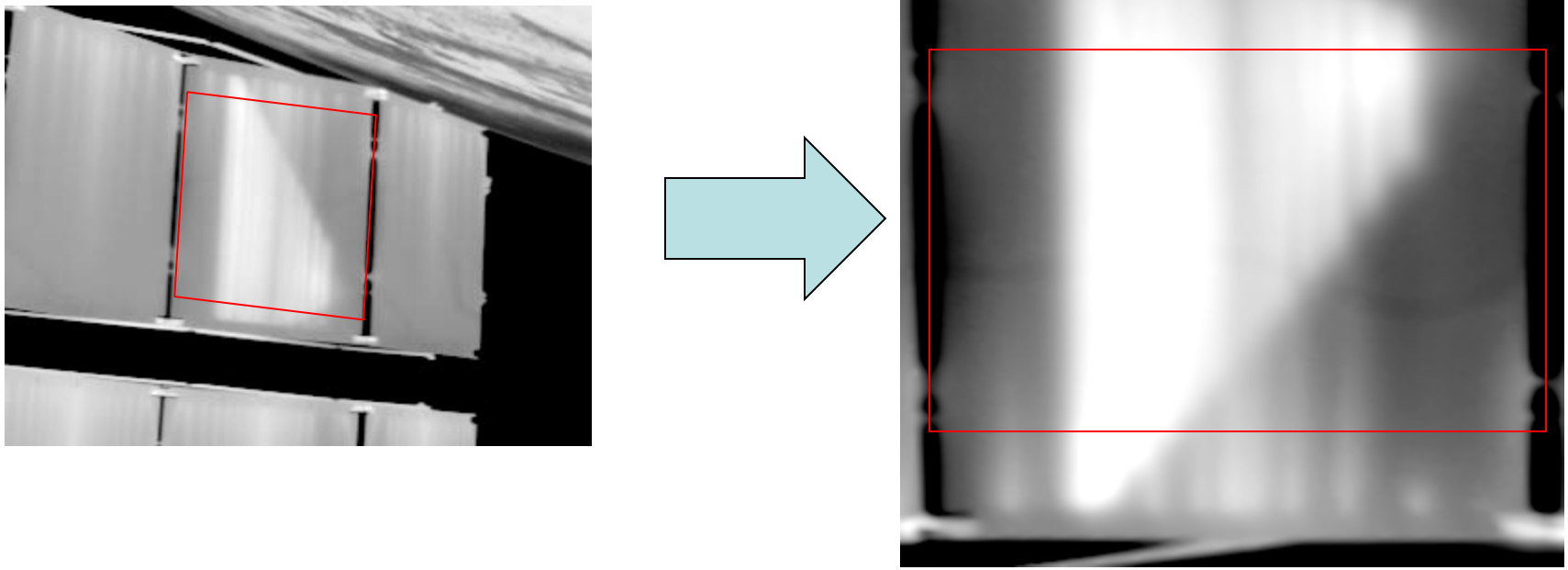
Affine Transform



Matlab routine and data processing provided by Dr. William Winfree and Patty Howell

Affine Transform

$$\begin{bmatrix} T_{1,1} & T_{1,2} & T_{1,3} \\ T_{2,1} & T_{2,2} & T_{2,3} \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} x' \\ y' \\ 1 \end{bmatrix}$$

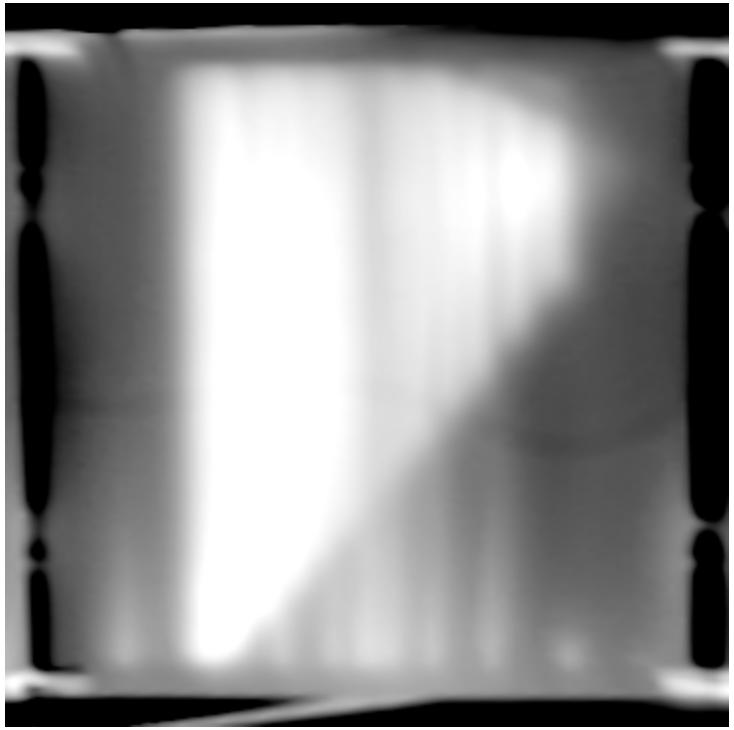


Each panel image is mapped as a rectangular image to extract data for comparison

$T_{1,1}$, $T_{1,2}$, $T_{1,3}$, $T_{2,1}$, $T_{2,2}$, $T_{2,3}$ *varied to give best mapping of four points on radiator to* fix size rectangle based on summed differences of coordinates of radiators and coordinates of corners on rectangle

Infrared Image and Laplacian of Infrared Image

Infrared Image



Laplacian

$$\Delta f = \frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2}$$

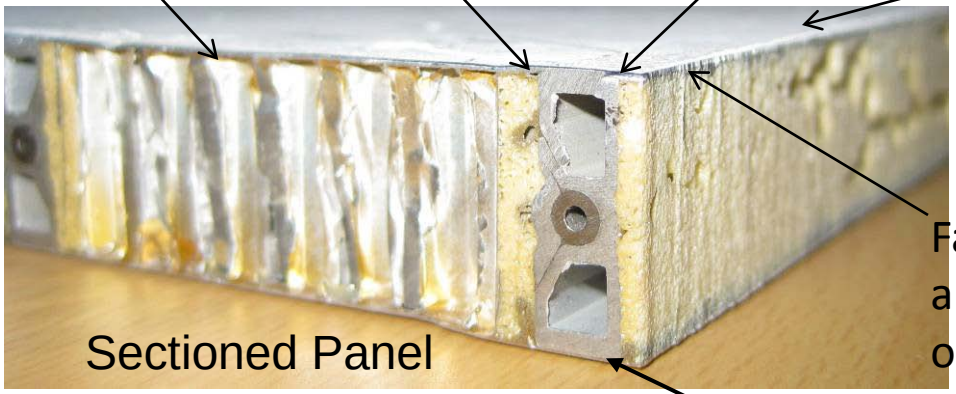
Laplacian enhances detection of temperature gradients.
Used to locate the internal Ammonia flow tube bracket locations for temperature mapping

IR Detection Areas of Interest

Facesheet core contact (no foam)

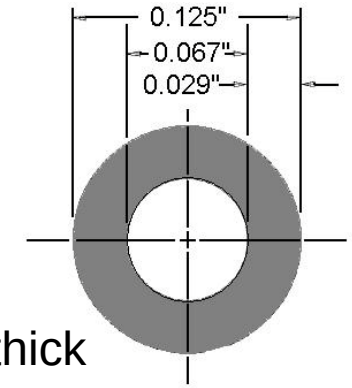
Unfilled foam cavity along chamfer

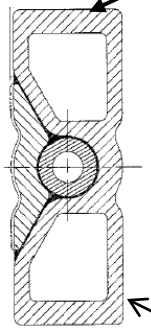
White paint



Facesheet to core and foam contact on either side of the bracket

Facesheet to bracket epoxy bond





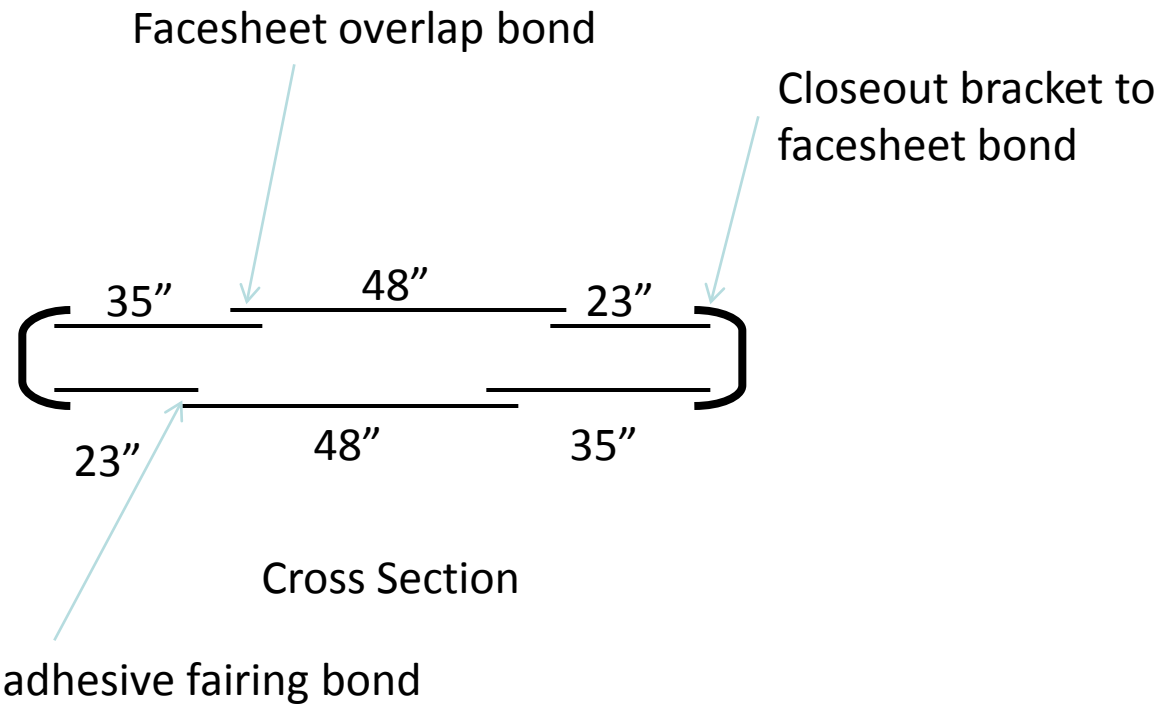
Flow Tube, Inconel 718

Aluminum facesheet 0.010” thick

Aluminum core

Aluminum bracket

IR Detection Areas of Interest

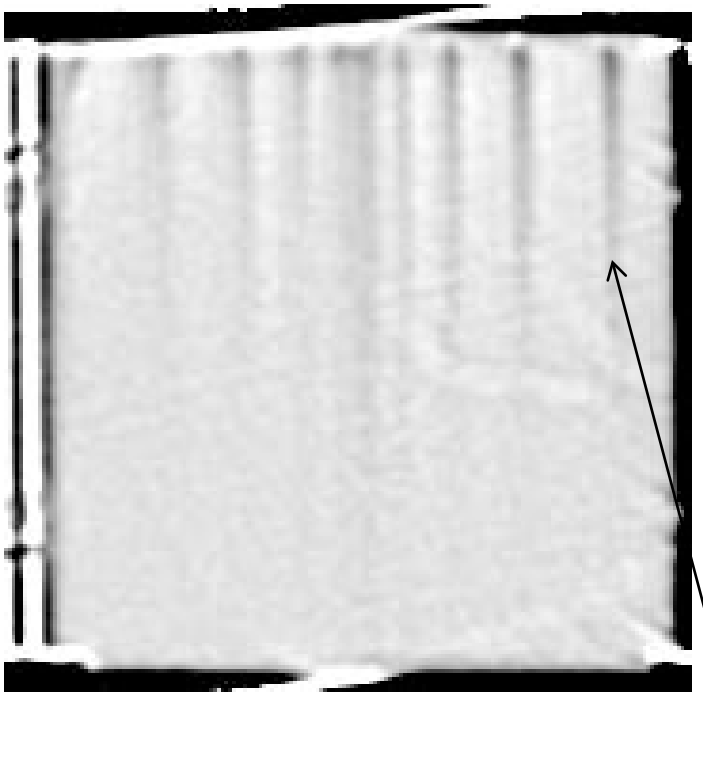


Panel size 10 ft x 13 ft

Comparison of Laplace of Infrared Images of Damage and Undamaged Panels

Backside

Damaged

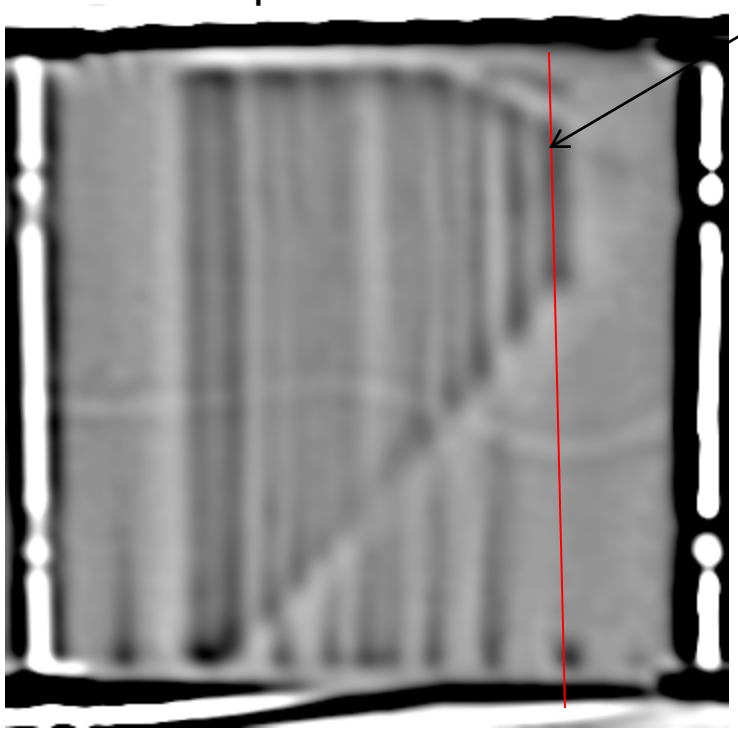


Undamaged

Flowtube location

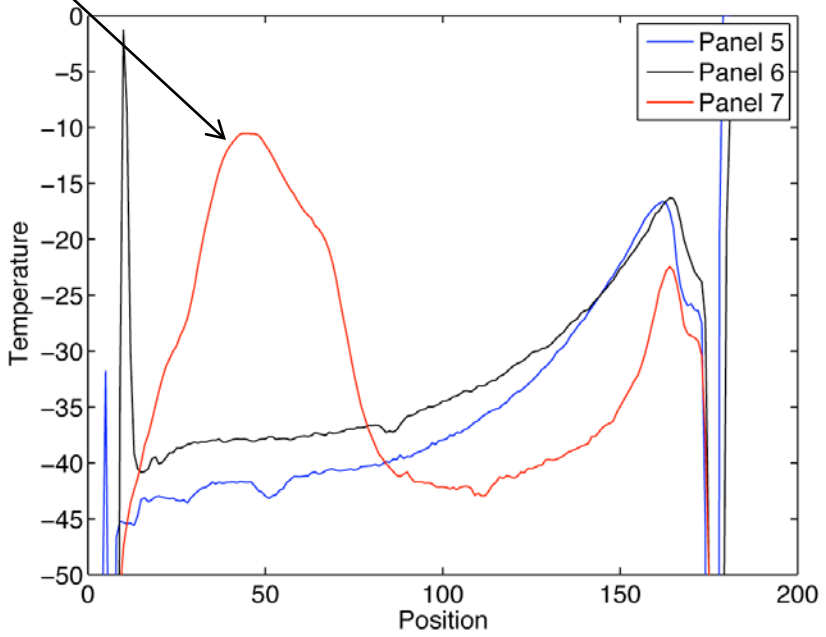
Comparison of Vertical Temperature Profiles Back Side of Disbonded Facesheet

Laplacian



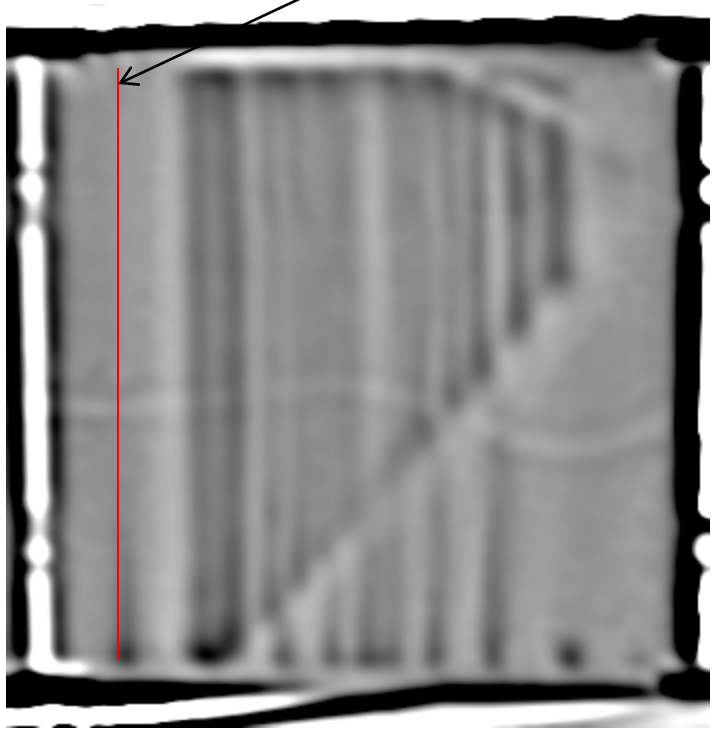
Hotside

Temperature profiles along
Centerlines of flowtube bracket vertical lines



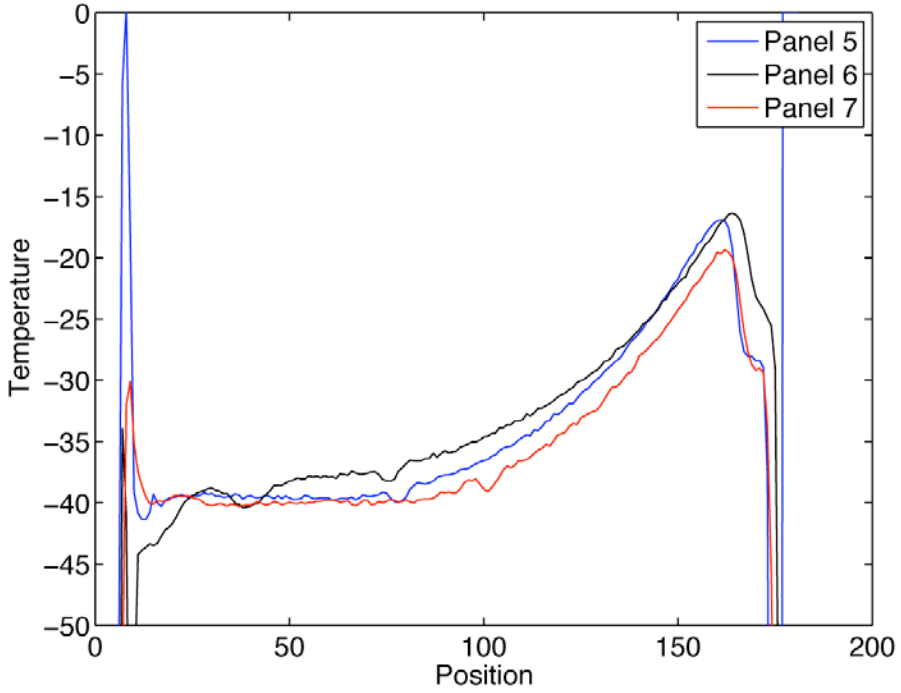
Comparison of Vertical Temperature Profiles of Same Flow tube location in neighboring panels

Location for temperature profile



Flow Direction

Hot side



Data analysis by Gary Reynolds

Summary of On-orbit IR Inspection

- **Infrared Imager Developed for RCC Inspection on orbit**
- **Successfully Demonstrated Damage Detection in**
- **RCC**
- **Imager Successfully Imaged ISS Radiator**
- **No Significant Indications Detected in Other ISS**
- **Panels**

Flash Thermography Inspection of Qualification Test Radiators

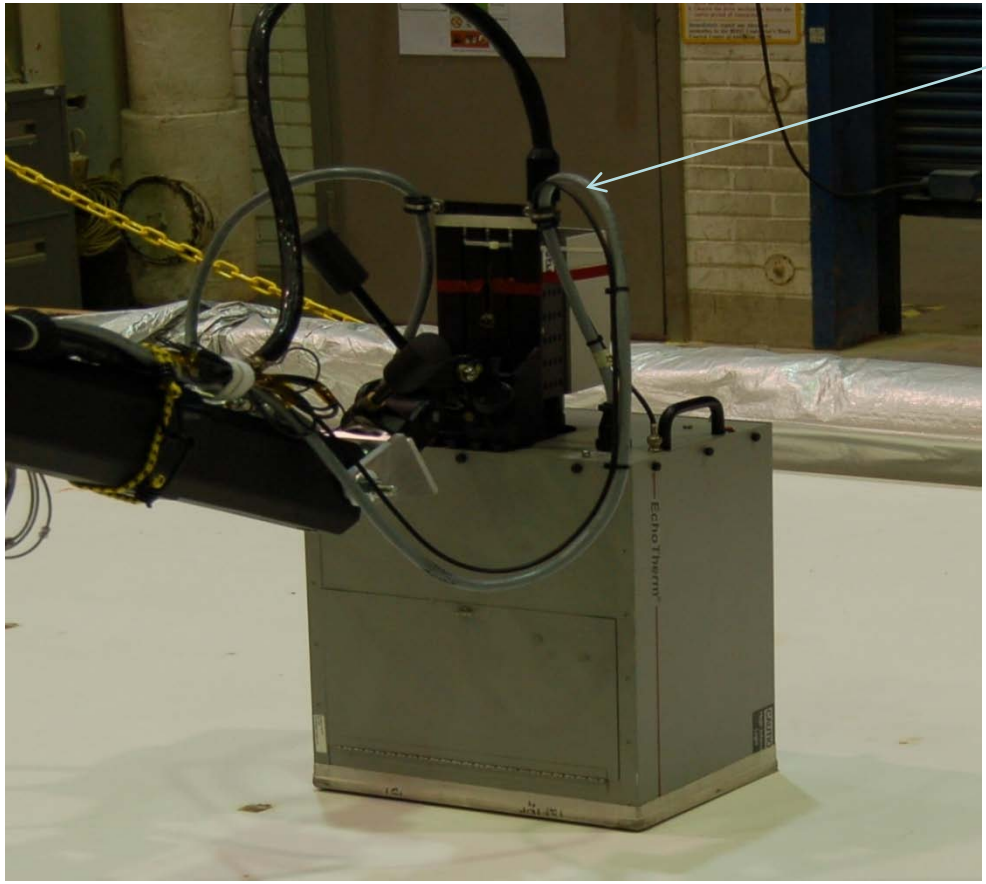
- A “root cause study” was undertaken to investigate the cause of the peeled facesheet of the ISS radiator.
- One of the actions was to determine if manufacturing process left debonds weakening the structure.
- Investigate feasibility of IR flash thermography in ground inspection of ISS radiator panels to detect debond of face sheet with honeycomb core, flow-tube bracket, overlapping facesheet, overlapping brackets, edge closeout.
- Note: IR thermography does not provide a measure of bond strength but can provide assessment of “thermal contact”.
  - Comparative qualitative image assessment of thermal contact at bondline.
  - Detect out-of-family indications using the Echotherm/Mosaic software
    - Use raw and second derivative image processing to evaluate the images

IR Thermography Set-up

Data acquisition and control

13 mm lens 120 Hz

IR Thermography Set-up – close up



Shot Area= 9” x 11”

Indication Types

- Narrow Linear Indications
- Large Rectangular Indications
- Interface De-bond Indications
- Small Circular Indications

- IR Data acquisition – Gary Reynolds
- IR Data Analysis – Walter Wilson and Ajay Koshti
- System support – Richard Morton, Bruce Harkness

Shot Layout

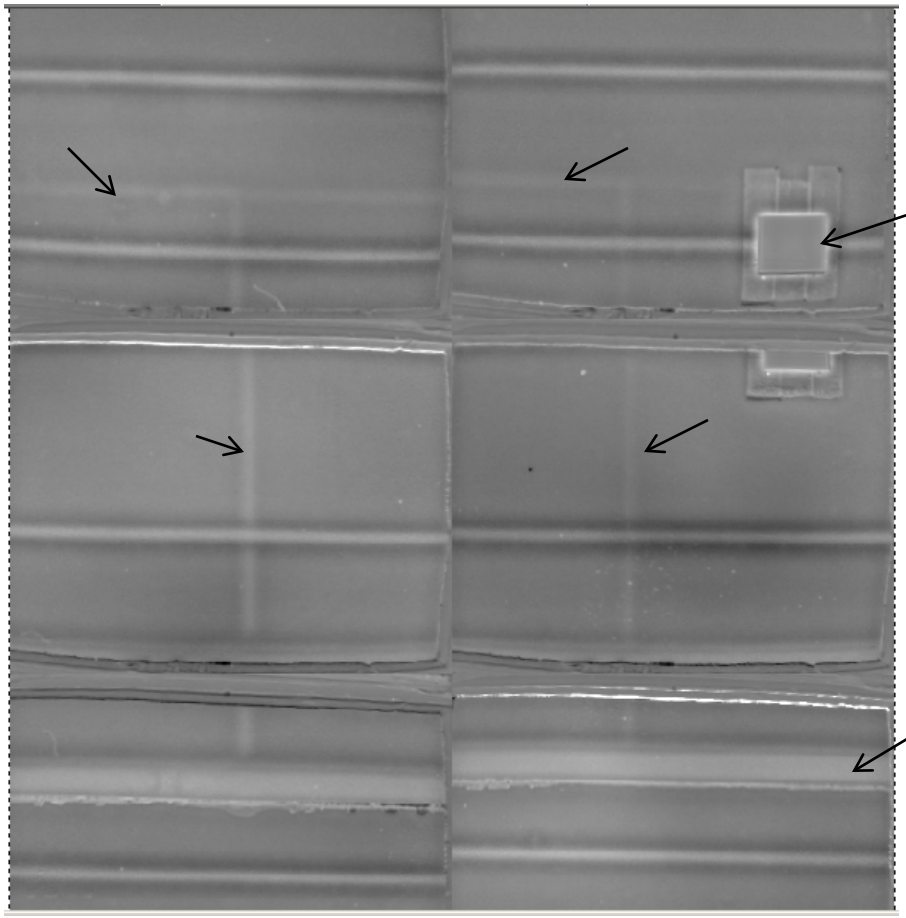
182	181	180	179	178	177	176	175	174	173	172	171	170	169	Edge
168	167	166	165	164	163	162	161	160	159	158	157	156	155	
154	153	152	151	150	149	148	147	146	145	144	143	142	141	Single Tube
140	139	138	137	136	135	134	133	132	131	130	129	128	127	
126	125	124	123	122	121	120	119	118	117	116	115	114	113	Face Sheet
112	111	110	109	108	107	106	105	104	103	102	101	100	99	
98	97	96	95	94	93	92	91	90	89	88	87	86	85	Multitube
84	83	82	81	80	79	78	77	76	75	74	73	72	71	
70	69	68	67	66	65	64	63	62	61	60	59	58	57	
56	55	54	53	52	51	50	49	48	47	46	45	44	43	
42	41	40	39	38	37	36	35	34	33	32	31	30	29	Face Sheet
28	27	26	25	24	23	22	21	20	19	18	17	16	15	Single Tube
14	13	12	11	10	9	8	7	6	5	4	3	2	1	Edge

10 ft x 13 ft

Narrow Linear Indications

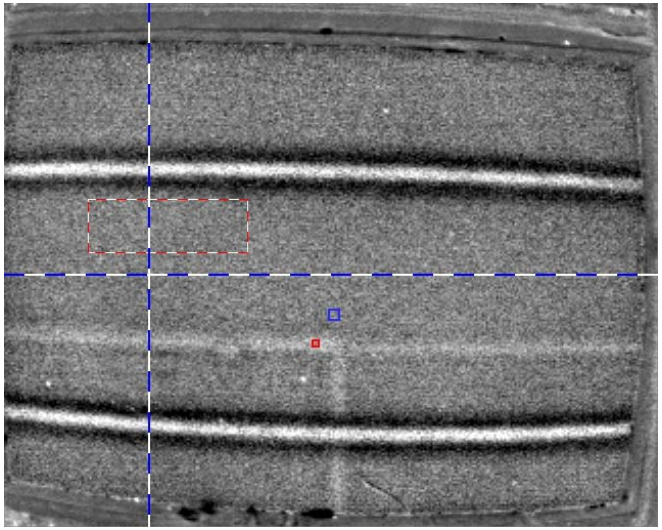
- Often Span Multiple Shots
- Film Adhesive Overlap Areas (more material)
- Show Up in Early Frames (10+)
- Tube signatures show through.
- Often ‘dead-end’ in face sheet overlap.
- Not an anomaly

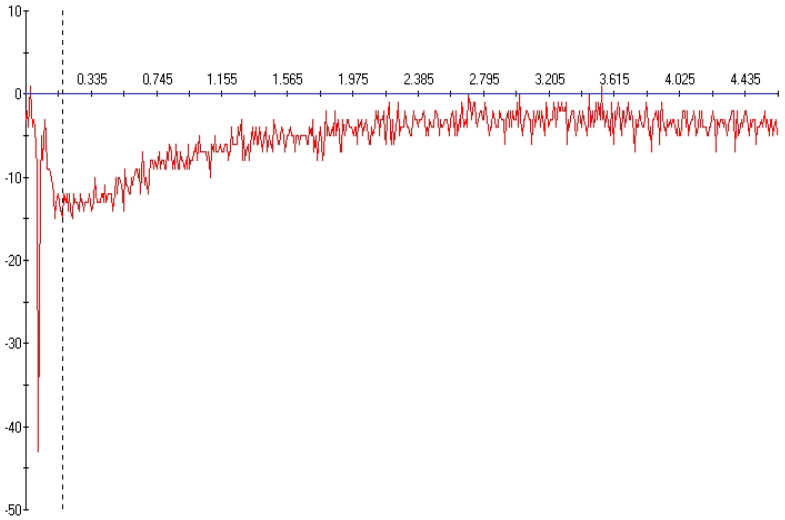
Typical Thin Linear Indications
Frame 26 2D



Panel 1B

Adhesive Sheet Overlap





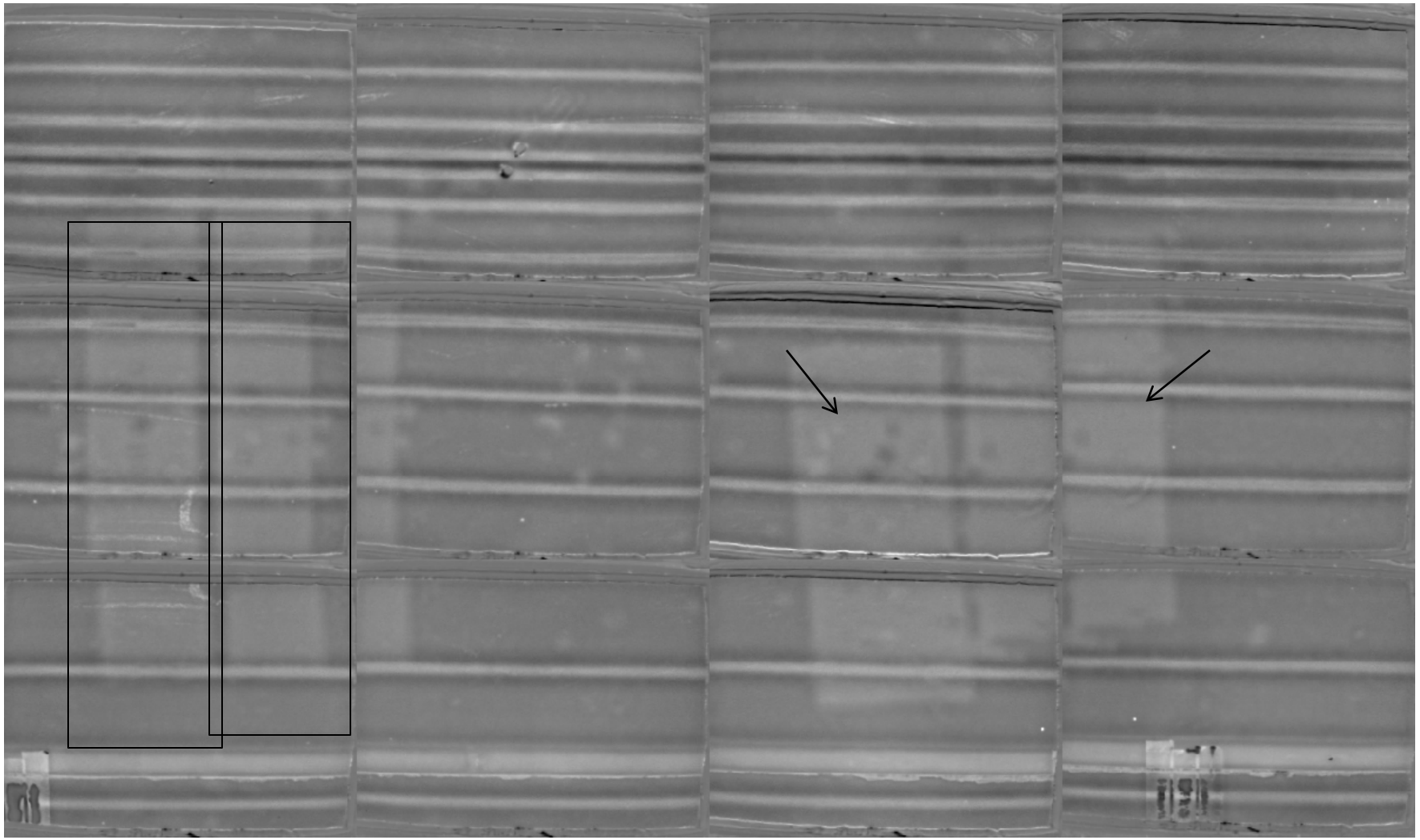
2D image

Comment: Provides negative contrast (cold area) due to additional adhesive

Large Rectangular Indications

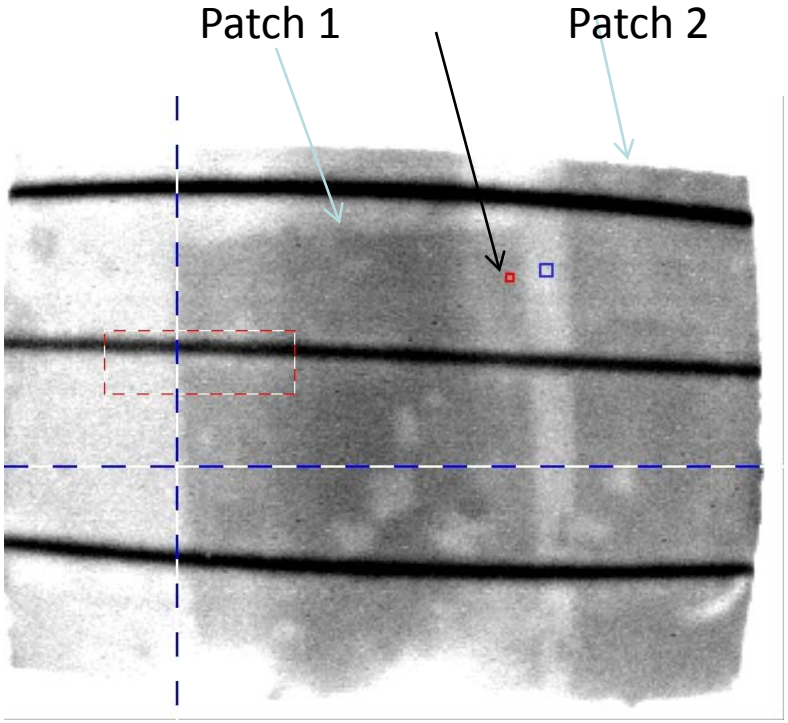
- Show Up Early
- Only Appear on Panel 2B
- Tube signatures evolve through these indications so they aren’t very thick
- Most likely ‘patches’ in film adhesive

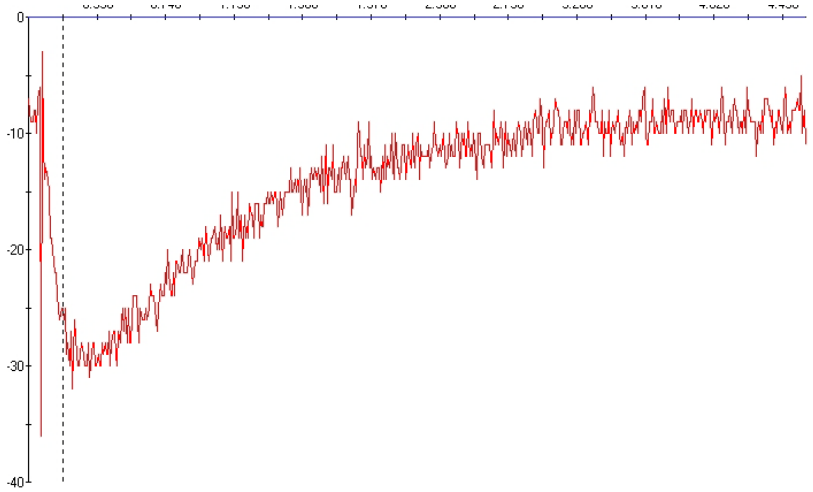
Typical Large Rectangular Indications
Frame 45 2D



Panel 2B

Additional Adhesive Patch





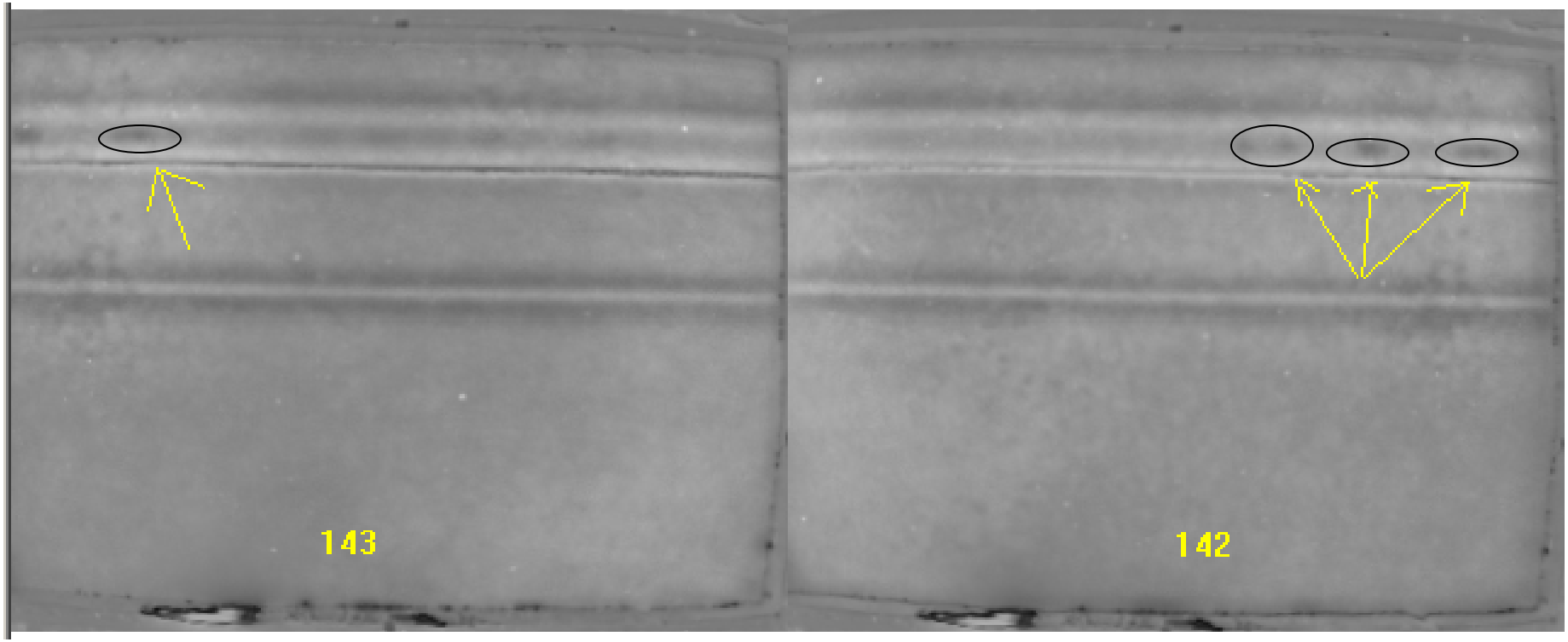
Red dot on the patch
Blue outside the patch

Comment: Provides a negative contrast (cold area) due to additional adhesive layer or layer of other material

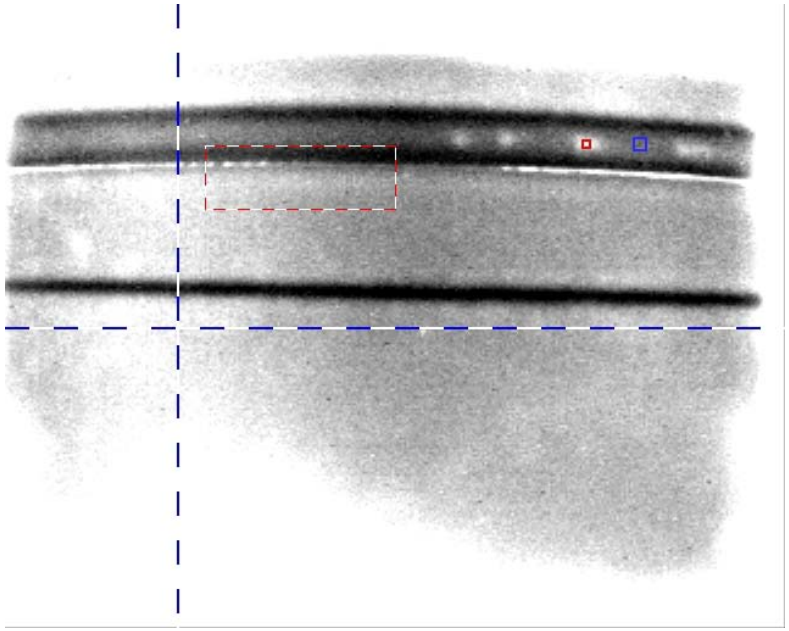
Face Sheet Bond Anomalies

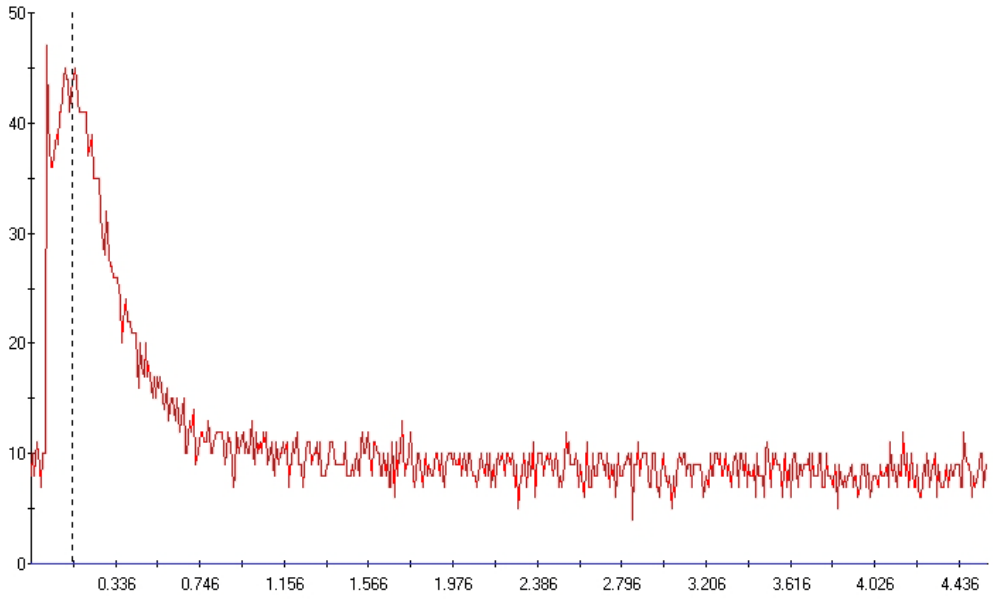
- Show up Early
- Show up hot/bright in Raw image indicating poor thermal contact
- Evident boundary lines and timing indicate that they occur in between face sheets where facesheets overlap

Face Sheet Debonds
Panel 4a Frame 15 2D



Suspect Void/Unbond at Facesheet Overlap

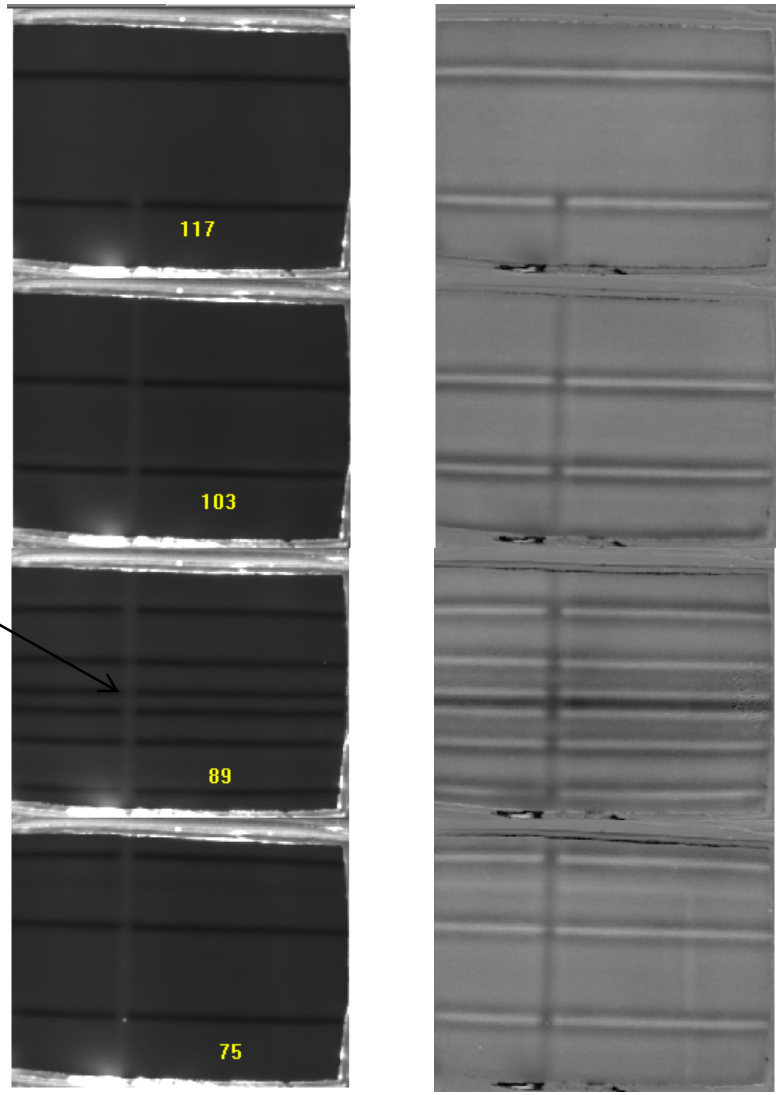




Raw Image

Comment: Warm spot indicating a void/unbond

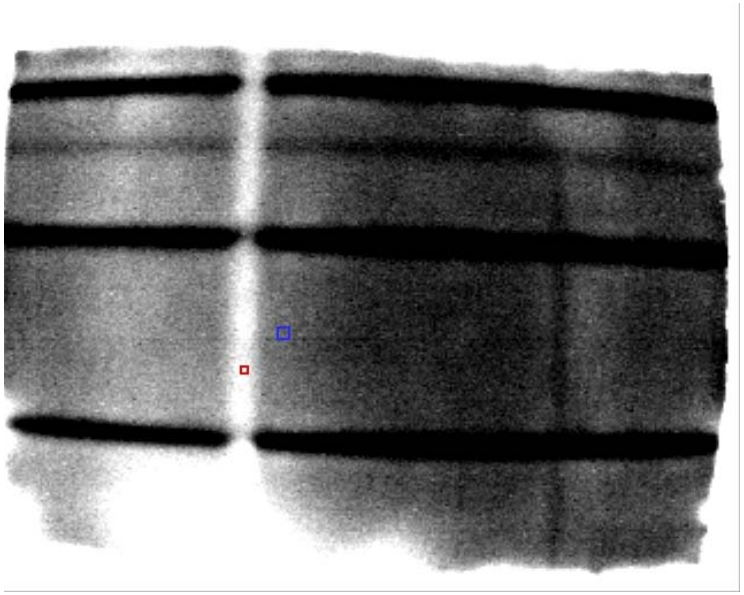
Linear Indication – Lack of Adhesive
Frame 30 Raw and 2D

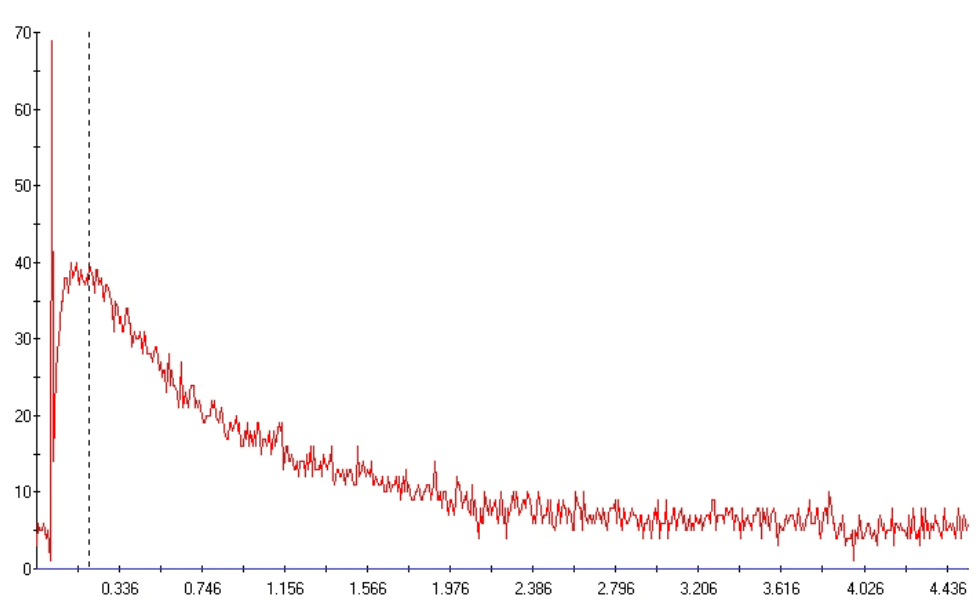


Linear indication

Panel 8A

Lack of Adhesive or Debond





Raw Image

Comment: Provides positive contrast (Hotspot) due to lack of adhesive or gap

Summary of Flash Thermography Inspection

- Several non-flight qualification test radiators were inspected using flash thermography
- Flash thermography data analysis used raw and second derivative images to detect anomalies (Echotherm and Mosaic)
- Simple contrast evolutions were plotted for the detected anomalies to help in anomaly characterization
- Many out-of-family indications were noted
  - Some out-of-family indications were classified as cold spot indications and are due to additional adhesive or adhesive layer behind the facesheet
  - Some out-of-family indications were classified as hot spot indications and are due to void, unbond or lack of adhesive behind the facesheet
- The IR inspection helped in assessing expected manufacturing quality of the radiators